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Mesoscale Environment Factors in the D. C. Area Tornado Event of 24 September 2001

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1. Introduction

Tornadoes that cause deaths in the Maryland and northern Virginia area are rare events. In Maryland during the period 1950-2000, only 2 deaths occurred from tornadoes. Prior to 2001, the last deaths from a tornado in the immediate vicinity of the District of Columbia (D.C.) occurred in 1979. But recently, tornado events on 9/24/01 and 4/28/02 have claimed the lives of 5 people in Maryland.

This paper reviews the tornado event on 9/24/01 from a forecasting perspective at the Storm Prediction Center (SPC). That afternoon, two different supercells produced strong and violent tornadoes in the northern Virginia-central Maryland area, including an F3 tornado (Fig. 1) that killed 2 people on the Maryland side of the D.C. area. A tornado watch was issued well in advance of the tornadoes, even though the synoptic and mesoscale settings leading up to the event were subtle.

Detection of a mesoscale low pressure area (mesolow) was important in forecasting this event, along with recognition of some environment aspects that were favorable for tornadoes. This case is a good example combining traditional analysis of surface features and their evolution (e.g., Moller 1980) with assessment of environment factors more recently found to be associated with tornadic supercells (e.g., Rasmussen and Blanchard 1998).

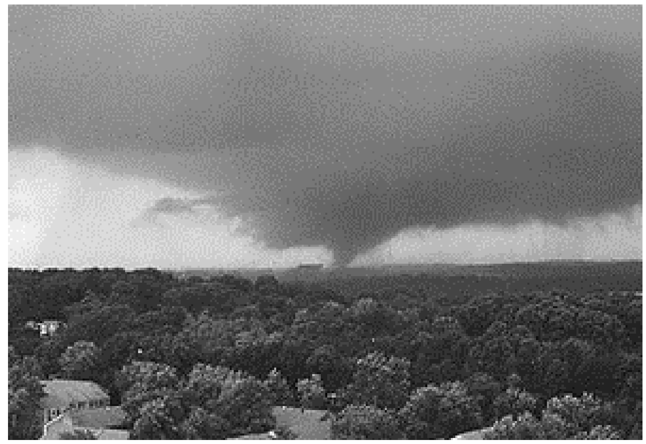

Figure 1. Photo of College Park tornado, rated F3, near the University of Maryland at about 2125 UTC. Courtesy of Washington Post and Ming-Ying Wei.

2. Synoptic setting

The 500 mb analysis at 12 UTC on 9/24/01 (Fig. 2) showed a sharp long wave trough centered on the Mississippi Valley, with moderate southwesterly flow (30-40 kts) extending from Alabama through the mid-Atlantic states. At mid morning, a surface cold front (Fig. 3) extended from eastern Ohio to Mississippi, with general cloudiness and non-severe convection well ahead of the front from Georgia to western Virginia. Low-level moisture appeared significant with surface dew points above 70°F along the coast from the Carolinas into Maryland, but lapse rates aloft were generally weak.

Although cloudiness was widespread, a few breaks in the clouds seemed likely from central North Carolina into central Virginia during daytime heating. Despite the weak lapse rates, with low-level moisture in place and some surface heating expected, surface-based CAPE values around 1500 J kg^{-1} or larger appeared possible over parts of North Carolina and Virginia. This would make for a weak to moderately unstable environment with little convective inhibition (CIN).

Scattered thunderstorms were expected to continue to develop well ahead of the upper trough and cold front.

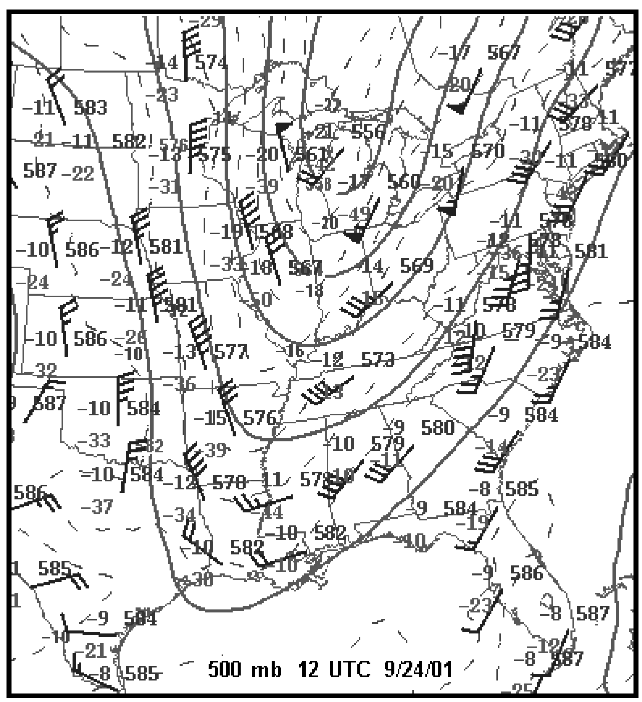

Figure 2. 500 mb chart at 12 UTC 9/24/01. Height contours (lines) are drawn at 60 m height intervals, temperature (dashed lines) at 2°C intervals. Wind barbs are conventional, in knots.

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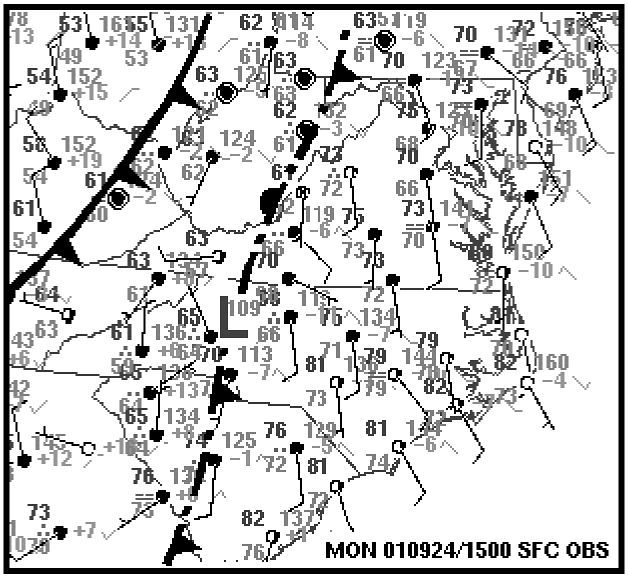

Figure 3. Surface analysis at 15 UTC 9/24/01, showing mesolow ("L") over western North Carolina. Pre-frontal convergence area is indicated by heavy dot-dash line with barbs; cold front is indicated by heavy solid line with barbs.

Vertical shear profiles, while not particularly strong, were expected to increase somewhat according to model guidance. So, while not overly impressive, the general synoptic setting appeared supportive of some severe thunderstorm activity during the day over the mid-Atlantic states.

3. Mesoscale factors

By late morning, using hourly surface analyses, SPC forecasters noticed a weak surface mesolow over western North Carolina (Fig. 3). This mesolow was located along a general north-south convergence area associated with scattered convection. It was expected that this feature would move northeast through the afternoon along the eastern slopes of the Appalachian Mountains with southwesterly flow aloft. From experience, SPC forecasters were aware that the mesolow would likely enhance any severe threat (Tegtmeier 1974) over the Virginia or North Carolina area during the afternoon.

Between 1630 and 17 UTC, several small convective cells developed over central North Carolina (not shown), exhibiting some weak midlevel rotation on radar. Given the forecast track of the mesolow with expected backing of surface winds ahead of this feature, and the resulting increase in vertical shear, the decision was made to issue a tornado watch for parts of Virginia and North Carolina.

Shortly after the watch was issued before 18 UTC, a storm developed in central Virginia near Charlottesville (cell "A" in Fig. 5), northeast of the advancing mesolow in an area of surface pressure falls (Fig. 4). This storm on radar rapidly took on supercell characteristics, and around 19 UTC produced a tornado (rated F4) in Culpeper County. Weaker tornadoes later occurred with the same storm in Fauquier County.

Another supercell (cell "B" in Figs. 5 and 7) developed around 19 UTC further east, to the southwest of Fredericksburg. Between 20 and 21 UTC, this storm produced weak tornadoes as it approached the District of Columbia, including an F1 tornado in Arlington. When the storm entered Maryland after 2115 UTC, immediately northeast of Washington D.C., it produced the F3 tornado at College Park (Fig. 1), resulting in 2 deaths.

Although several rotating storms developed across North Carolina and Virginia within a broad area of scattered convection, the only significant tornadoes occurred in association with the mesolow as it moved across central and northern Virginia. Hourly analyses also suggested that there was a subtle pre-existing boundary in the D.C. area ahead of the mesolow, oriented northwest to southeast (Fig. 6). This "coastal front" near the Potomac River appeared to focus pressure falls as the mesolow approached, and may have played a role in the D.C. area tornadoes.

4. Environment factors

In addition to indications from traditional surface analysis, derived fields of parameters such as storm-relative

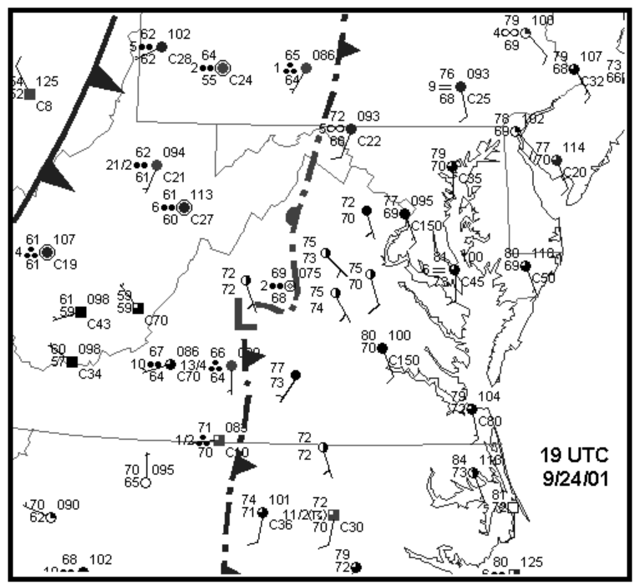

Figure 4. As in Fig. 3, except for 19 UTC, with closer view of Virginia/Maryland area.

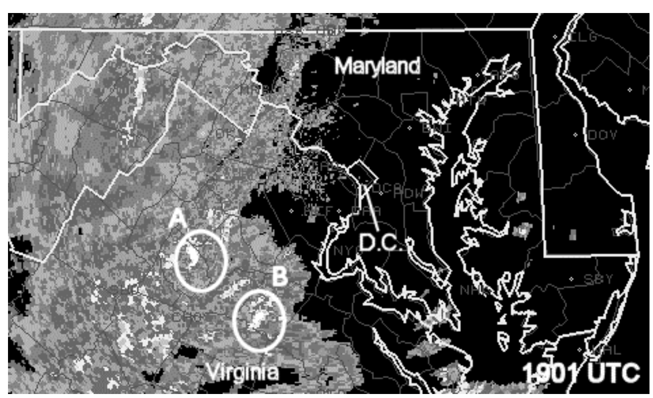

Figure 5. Radar image (base reflectivity, level 1) from Sterling, Virginia at 1901 UTC. Tornadic supercells are circled. Cell "A" produced a damaging tornado shortly after this image. Cell "B" later produced tornadoes in the immediate D.C. area

helicity (SRH, Davies-Jones et al. 1990) suggested that the backed wind fields northeast of the mesolow were associated with larger values of low-level wind shear known to be more favorable for tornado development (e.g., Davies and Johns 1993). Figure 8 shows a depiction from Eta model data (incorporating actual surface observations) of estimated 0-3 km SRH at early afternoon, indicating the moderately increased low-level shear over north central Virginia just prior to the first tornadoes. As a result, shear-CAPE combinations such as the energy helicity index (EHI, Hart and Korotky 1991; Davies 1993) and vorticity generation parameter (VGP, Rasmussen and Blanchard 1998) were locally maximized ahead of the mesolow (not shown), suggesting increased potential for storm rotation across this area.

RUC-2 model analysis profiles have been shown to provide useful estimations of storm environment for forecasters when actual soundings are not available (e.g., Thompson and Edwards 2002). The RUC-2 model analysis profile for KDCA at 21 UTC (Fig. 9) showed increased veering of the wind profile in the lowest 1 to 3 km, with larger amounts of SRH (200-300 m^2s^{-2}) than earlier suggested by the Eta model in Fig. 8. Combined with surface-based CAPE of around 1500 J kg^{-1}, the shear environment from this estimated profile appeared quite supportive of supercells and possible tornadoes. Both Eta and RUC-2 profiles showed this increase in SRH over the D.C. area during the afternoon, highlighting the importance of paying close attention to changes in the mesoscale environment on an hour-by-hour basis.

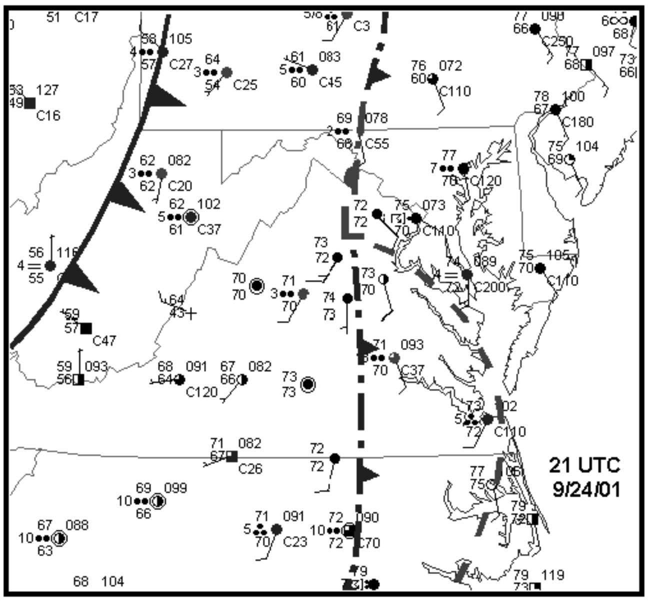

Figure 6. As in Fig. 4, except for 21 UTC. Heavy dashed line extending southeast of mesolow is possible location of subtle "coastal" boundary suggested by wind field.

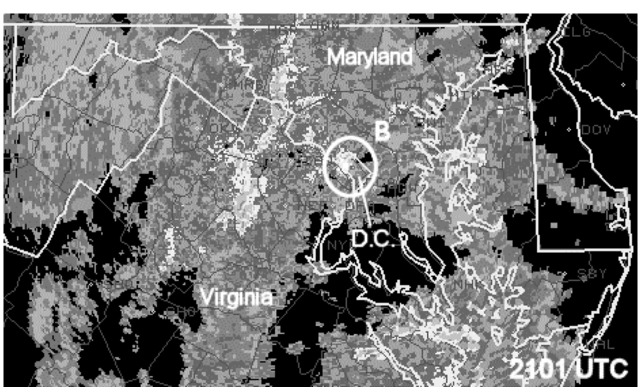

Figure 7. As in Fig. 5, except for 2101 UTC. Cell 'B' (circled) produced a killer F3 tornado at College Park, Maryland about 15 to 20 minutes after the time of this image.

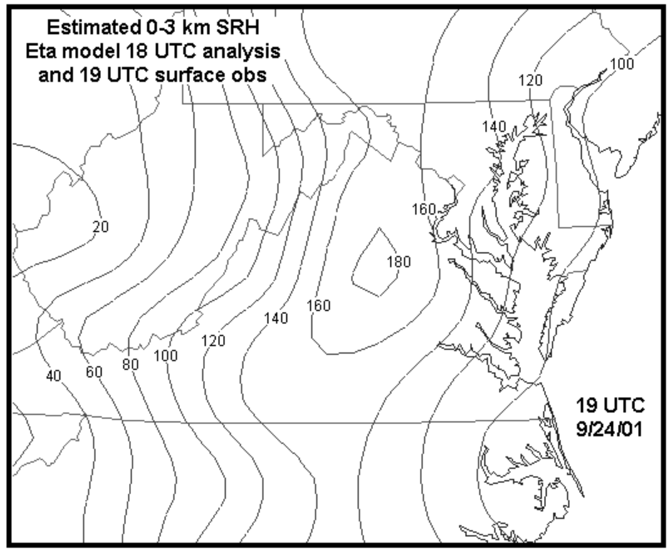

Figure 8. 0-3 km SRH field from Eta analysis at 18 UTC 9/24/01, merged with actual surface observations at 19 UTC. Contours are at intervals of 20 m^2s^{-2}. Observed warm sector storm motions are used.

Notice also the moist low-levels of the profile in Fig. 9, including the very low LCL (lifting condensation level) and LFC (level of free convection). From Rasmussen and Blanchard (1998) and Markowski et al. (2002), increased boundary layer humidity (suggested by a low LCL) is an important factor for supercell tornado development. In addition, the low LFC height, small CIN, and large low-level CAPE suggested a low-level thermodynamic environment favorable for tornadoes based on associations of these parameters with supercell tornado cases (Davies 2002, this volume).

5. Discussion and summary

The synoptic features and environment in this case were subtle compared to the more recent tornado event on 4/28/02 in Maryland that killed 3 people south of the D.C. area. In that case, shear and CAPE profiles were impressive and evident over a large area, with tornado watches in effect over several states. In the 9/24/01 case, clouds were widespread, lapse rates generally weak, and shear profiles unimpressive except in a localized area to the northeast of the mesolow. Careful analysis of mesoscale features, knowledge of potential impact of those features on the localized environment, and experience with similar settings were primary factors that led to issuance of a tornado watch by SPC.

This event reaffirms the importance of careful hourly mesoscale analysis of surface maps in assessing severe weather potential, and how mesoscale details can play a role in

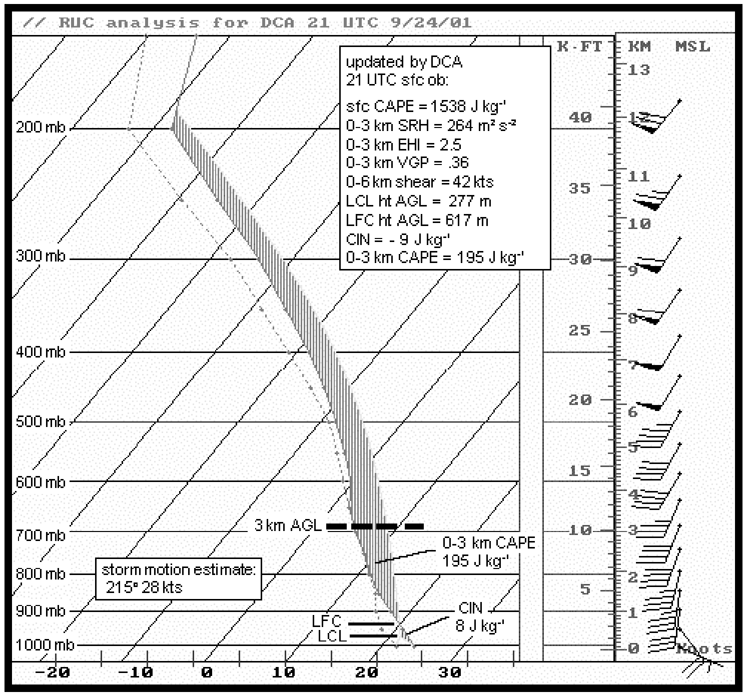

Figure 9. SkewT log*p* plot of RUC-2 analysis profile for Washington National Airport at 21 UTC 9/24/01. Boundary-layer is updated by actual surface observation at 21 UTC. Selected parameter values are shown; thermodynamic parameters were computed using a surface-based parcel without the virtual temperature correction.

significant tornado events. In this case, the mesolow needed to be identified hours ahead of time to help in the forecast process prior to a tornado watch being issued by SPC. Unfortunately, hourly surface analysis is not routine in most operational forecast settings, possibly due to time and paper reduction issues.

Surface pressure falls often signal the location and trend of significant severe weather (e.g., Moller 1980). During this event, pressure falls across northern Virginia into central Maryland highlighted in advance the area where significant tornadic supercells occurred. The use of surface pressure falls is not widely acknowledged as a severe weather resource, but has been found at SPC to be a consistently useful short-term forecast tool.

In addition to mesoscale analysis, derived model fields and profiles for this case proved helpful in confirming that the environment in a localized area northeast of the mesolow was more favorable for supercell tornadoes. Low-level shear, CAPE, and low-level thermodynamic parameters all appeared supportive of tornadoes across northern Virginia and the D.C. area shortly before the event.

In summary, this case is a good example of effective merging of powerful "old school" analysis methods (e.g., mesoscale surface analysis) with assessment of wind and thermodynamic factors more recently recognized as having importance in supercell and tornado forecasting. Both are important in severe weather forecasting.

7. Acknowledgements

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